

# New Results from CLEO

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Plenary Submission to XXXth International Conference on  
High Energy Physics

15 September 2000

## Abstract

The latest results from the CLEO collaboration are summarized. An update on the status of the upgraded CLEO III detector is also included.

## 1 Introduction

The  $\Upsilon(4S)$  has proved to be a rich mine of physics results. The study of rare  $B$  decays has been a constant challenge to beyond standard model extensions. Semileptonic  $B$  decays have provided crucial information on the CKM matrix elements  $V_{cb}$  and  $V_{ub}$ . Hadronic  $B$  decays are also a challenge and provide insight into QCD. With the beginning of the programs at the asymmetric  $B$  factories at SLAC and KEK the new avenue of CP-violation studies has opened up. There is also a wealth of physics under the resonance especially in charm mesons, charm baryons, and taus. The energy range is also ideally suited to two photon production studies, and of course the study of the properties of the  $\Upsilon$  and other  $b\bar{b}$  resonances themselves. CLEO entered into its twentieth year of data taking at the end of 1999. I summarize here the latest, that is since the 99-00 winter conference season, results from CLEO. Even limiting myself to this time slice leaves no room for tau physics and many results can be only referenced.

I will first discuss our new results in rare  $B$  decays where we have an unambiguous observation of the gluonic penguin mode,  $B \rightarrow \phi K$ , new limits on  $B$  decays to  $\pi^0\pi^0$ , a pair of charged leptons,  $\tau\nu$ , and  $K\nu\nu$ . Turning to semileptonic  $B$  decays I present our preliminary results on  $V_{cb}$  in  $B \rightarrow D^*\ell\nu$  decay, and a new measure of  $B$  mixing parameters combining

a lepton tag with a partial reconstruction hadronic tag. In hadronic  $B$  decays we have observed  $B \rightarrow D^{(*)}4\pi$  and studied the resonance substructure of the  $4\pi$  system. We have many new results on  $B \rightarrow$  Charmonium including observations of  $B \rightarrow \eta_c K$  and limits on  $\chi_{c0}$  in an attempt to understand our anomalous results on  $B \rightarrow \eta$ . Also we test charmonium production models by observing  $B \rightarrow \chi_{c1}$  and limiting  $\chi_{c2}$ . We have measurements of  $B \rightarrow D_s^{(*)}D^*$  and evidence for  $D_s^{(*)}D^{**}$ . In the  $D_s D^*$  decay and  $D^*4\pi$  we measure the polarization of the  $D^*$  to test a prediction of the factorization ansatz. We have observed the first exclusive  $B$  decays to nucleons in  $D^{*-}p\bar{p}\pi^+$  and  $D^{*-}p\bar{n}$ . In charm physics we have observed wrong sign  $D^0 \rightarrow K\pi\pi^0$  and are working hard on more  $D\bar{D}$  mixing and Doubly Cabibbo Suppressed Decay (DCSD) studies. In charm baryons we have many new results including first observations of the  $\Sigma_c^{*+}$  and the pair  $\Xi_{c1}^+$  and  $\Xi_{c1}^0$ . These complete the set of  $L = 0$  charm baryons, the bulk of which were first observed by CLEO. In resonance physics we have a measure of the rate for the  $\Upsilon(4S)$  to decay to charged and neutral  $B$  meson pairs. We have measurements of  $\eta_c$  parameters based on its two photon production to investigate a puzzle in PQCD. Finally CLEO went through a major upgrade to the third major version of our detector. This began taking physics data in July of 2000, and I will briefly review the status of CLEO III.

The results discussed below are based on the CLEO II data set taken with the CLEO II detector from 1989 to 1999. The detector is described in detail elsewhere. [1] About two thirds of the data were taken from 1995 to 1999 in the CLEO II.V configuration which replaced the innermost straw-tube detector of CLEO II with a high precision silicon vertex detector.[2] Most of the analyses discussed use the entire CLEO II data set with exceptions for systematic error limited studies and analyses that depend on the precision vertex measuring capabilities only available in CLEO II.V. The total data set has an integrated luminosity of roughly 14/fb with two thirds taken at a center of mass energy of about 10.58 GeV on the peak of  $\Upsilon(4S)$  resonance, corresponding to roughly ten million  $B\bar{B}$  events, and one third taken at an energy 60 MeV below the  $\Upsilon(4S)$  peak and well below the  $B\bar{B}$  threshold.

## 2 Rare $B$ Decays

### 2.1 $B \rightarrow \phi K$

The decay  $b \rightarrow sg$  produced by the gluonic penguin can be uniquely tagged when the gluon splits into an  $s\bar{s}$  pair as no other  $b$  decay can produce this final state. The mode  $B \rightarrow \phi K$  is one such tag of the gluonic penguin and its rate is a vital piece to the rare  $B$  decay puzzle. We search for the signal in both the charged and neutral modes pairing a reconstructed  $\phi \rightarrow KK$  candidate with a charged track that has a specific ionization ( $dE/dx$ ) and time-of-flight consistent with a kaon or a reconstructed  $K_s^0 \rightarrow \pi\pi$  candidate. We extract the yield of signal events by performing an unbinned, maximum likelihood fit to the six variables shown in Figure 1 where the PDF for the signal is taken from simulation and the background is taken from off resonance data. The yield, significance, efficiency for this procedure and the preliminary branching fractions for the two modes are displayed in Table 1. Including

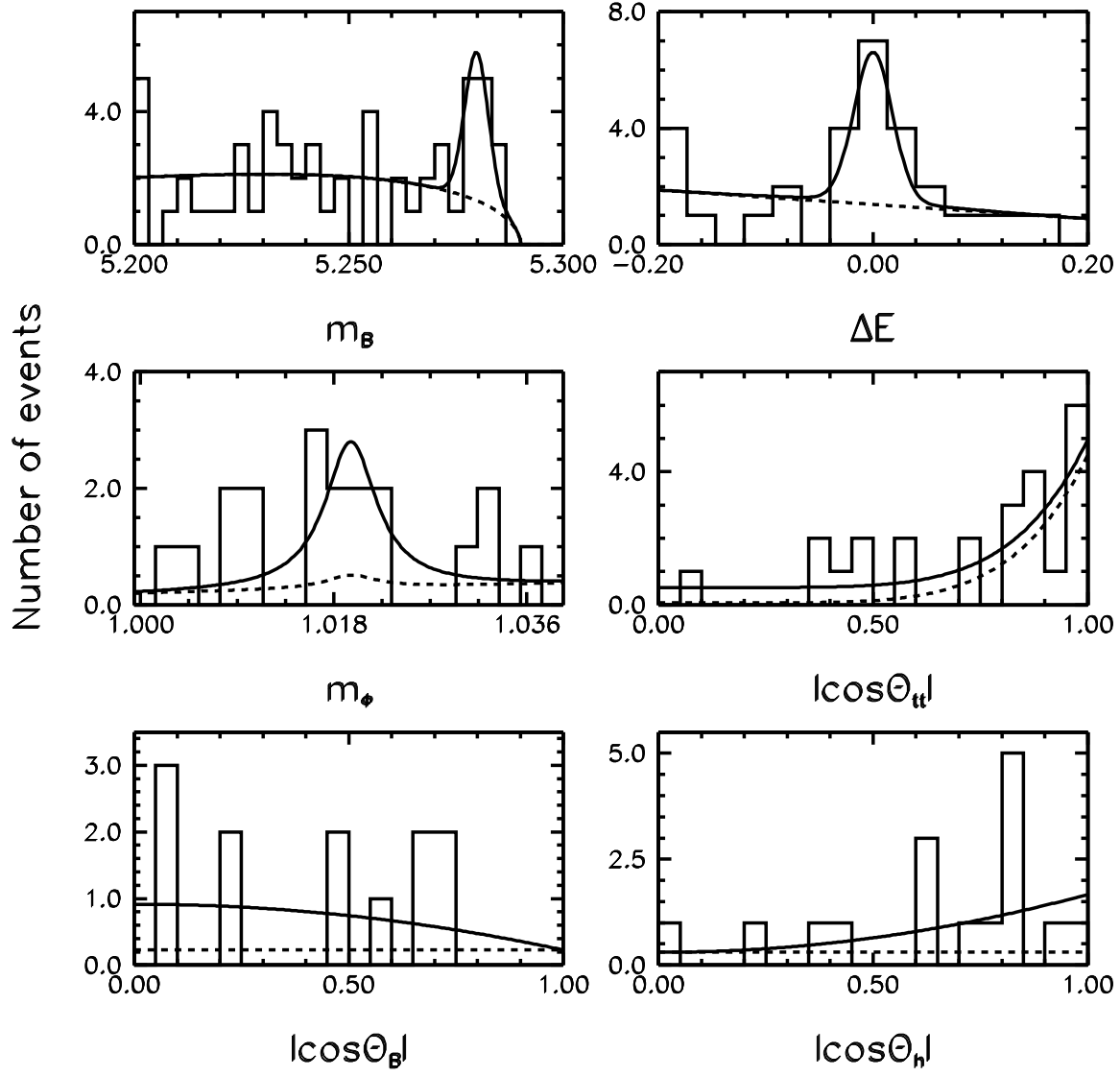


Figure 1: Projections of the  $\phi K^-$  data on the six variables used in the maximum likelihood fit. The solid lines show the total fit while the dashed lines show the contribution of the background.

Table 1: Results of likelihood fit. Note that the efficiencies do not include any branching fractions

	$B^- \rightarrow \phi K^-$	$B^0 \rightarrow \phi K_s^0$
Signal Yield	$15.8^{+6.1}_{-5.1}$	$4.3^{+2.0}_{-2.1}$
Significance ( $\sigma$ )	4.72	2.94
Efficiency (%)	49	31
B ( $\times 10^{-6}$ )	$6.4^{+2.5}_{-1.8}$	$5.9^{+4.0}_{-2.9}$

Table 2: Limits on the indicated branching fractions from the CLEO search for  $B^0 \rightarrow \ell\ell$  compared with the predicted rates from the Standard Model.

Mode	90% C.L.U.L.	Prediction[8]
$e^+e^-$	$8.3 \times 10^{-7}$	$1.9 \times 10^{-15}$
$e^\pm\mu^\mp$	$15 \times 10^{-7}$	0
$\mu^+\mu^-$	$6.1 \times 10^{-7}$	$8.0 \times 10^{-11}$

systematics, we interpret the neutral mode as an upper limit of  $1.2 \times 10^{-5}$  at the 90% C.L., measure  $(6.4_{-2.1}^{+2.5+0.5}) \times 10^{-6}$  for the charged mode, and  $(6.2_{-1.8}^{+2.0+0.7}) \times 10^{-6}$  for the average. The average has a significance of  $5.56\sigma$ . The systematics are dominated by the fit procedure. All the results are preliminary. They agree with theoretical expectations for  $B \rightarrow \phi X_s$ [3] if the  $K$  fraction of  $X_s$  is 6-10%.

## 2.2 $B \rightarrow \pi^0\pi^0$

Continuing our program of search for all the  $B \rightarrow \pi\pi$ ,  $K\pi$ , and  $KK$  modes[4] to try to gain information on the angles of the standard unitarity triangle,[5] we have a new preliminary results on the all neutral mode  $B^0 \rightarrow \pi^0\pi^0$ . No signal is observed, it is expected to be much smaller than our previously observed  $B^0 \rightarrow \pi^+\pi^-$  signal as it is color suppressed, and we set a 90% C.L. upper limit of  $5.7 \times 10^{-6}$  on the branching fraction. It is interesting to note that in this analysis we have to account for possible feed down from  $B \rightarrow \pi\rho$  modes some of which we have recently observed.[6]

## 2.3 $B \rightarrow \ell\ell$

Higgs doublet and SUSY extensions to the Standard Model and leptoquark models predict a large enhancement in the rate of neutral  $B$  decays to two charged leptons. The leptoquark models can even allow the lepton flavor violating mode  $B^0 \rightarrow e^\pm\mu^\mp$  to occur. We have searched for these modes and see no evidence for them.[7] The results are summarized in Table 2.

## 2.4 $B \rightarrow \tau\nu$ and $B \rightarrow K\nu\nu$

The charged  $B$  can decay via annihilation to a  $W$  of its two internal quarks to a lepton and neutrino. The observation and measurement of these decays are among the most important rare  $B$  decays because they provide a unique constraint on the unitarity triangle when combined with the  $B$  mixing measurements[9] and provide the cleanest way to measure the decay constant,  $f_B$ . At CLEO we have searched for the decay  $B \rightarrow \tau\nu$ , the largest mode because of helicity suppression, by looking for a single track from the  $\tau$  decay opposite an inclusively reconstructed charged  $B$  decay to  $D$  or  $D^*$  plus up to four pions only one of which

is allowed to be a  $\pi^0$ . [10] We look for eight decay modes of the  $D$ . We calibrate this tagging efficiency by running the analysis on a  $B \rightarrow D^* \ell \nu$  sample and measure the tagging efficiency with a relative accuracy of 24% where this error is dominated by the statistics of the check sample. The result is shown in Figure 2 in terms of the difference between the energy of the tagging  $B$  and the beam energy. Also shown is the expected distribution from simulated signal events, and the result of a likelihood fit for the most probable branching fraction. We obtain an upper limit of  $8.4 \times 10^{-4}$  for the branching fraction at 90% C.L. Standard model expectations are in the mid- $10^{-5}$  range.

This search can be easily modified to look for  $B \rightarrow K^\pm \nu \nu$  which can be mediated by an electroweak penguin. Single tracks that are consistent with leptons are excluded, as shown in Figure 2, and we obtain an upper limit on the branching fraction of  $2.4 \times 10^{-4}$  at 90% C.L.

### 3 Semileptonic $B$ Decays

#### 3.1 $|V_{cb}|$ in $B \rightarrow D^* \ell \nu$

The measurement of  $V_{cb}$  is vital to our understanding of the unitarity triangle as it sets the scale of the entire triangle. The favorite technique is to consider the decay  $B \rightarrow D^* \ell \nu$  in the context of the Heavy Quark Effective Theory (HQET). The prediction is that at the kinematic end point where the  $D^*$  is at rest with respect to the decaying  $B$ ,  $q^2$  is maximal and  $w \equiv v_B \cdot v_{D^*}$  is minimal at 1, the rate for the decay is proportional to  $(|V_{cb}|F(1))^2$ . Here  $F(w)$  is the universal form factor of HQET. Thus the strategy of this analysis is measure  $d\Gamma/dw$  for  $B \rightarrow D^* \ell \nu$ , extrapolate to the end point, and appeal to theory to calculate the proportionality to measure  $|V_{cb}|$ . In CLEO this analysis critically depends on the tracking efficiency for the low momentum pion from the  $D^*$  decay, is systematically limited mainly by our ability to measure this, and thus only uses the first third of the CLEO II data set, the data taken in the CLEO II configuration. It is preliminary and is documented more completely elsewhere. [11]

The  $d\Gamma/dw$  distribution is measured by fitting the distribution of  $\cos \theta_{B-D^* \ell}$  which can be computed from observed  $D^* \ell$  pairs and the known beam energy and  $B$  mass assuming the only missing particle from the  $B$  decay is a massless neutrino. Backgrounds are determined from the data from non- $B\bar{B}$  events using off resonance data and combinatorics from  $D^*$  sidebands. We use the simulation to model correlated backgrounds, where both the  $D^*$  and  $\ell$  are from the same  $B$  decay, uncorrelated backgrounds where they are from different  $B$  decays, and we ignore the small contribution from fakes. Combinatorics are the largest background source, about 6%, continuum and uncorrelated are about 4% each, and correlated background is about 0.5%. The result is shown in Figure 3. There remains a background of  $D^* X \ell \nu$  with contributions from  $B$  semileptonic decay to the so called  $D^{**}$  resonances and to non-resonant  $D^*$  plus at least one pion. These are modeled with the simulation and generously varied to test their systematic effect.

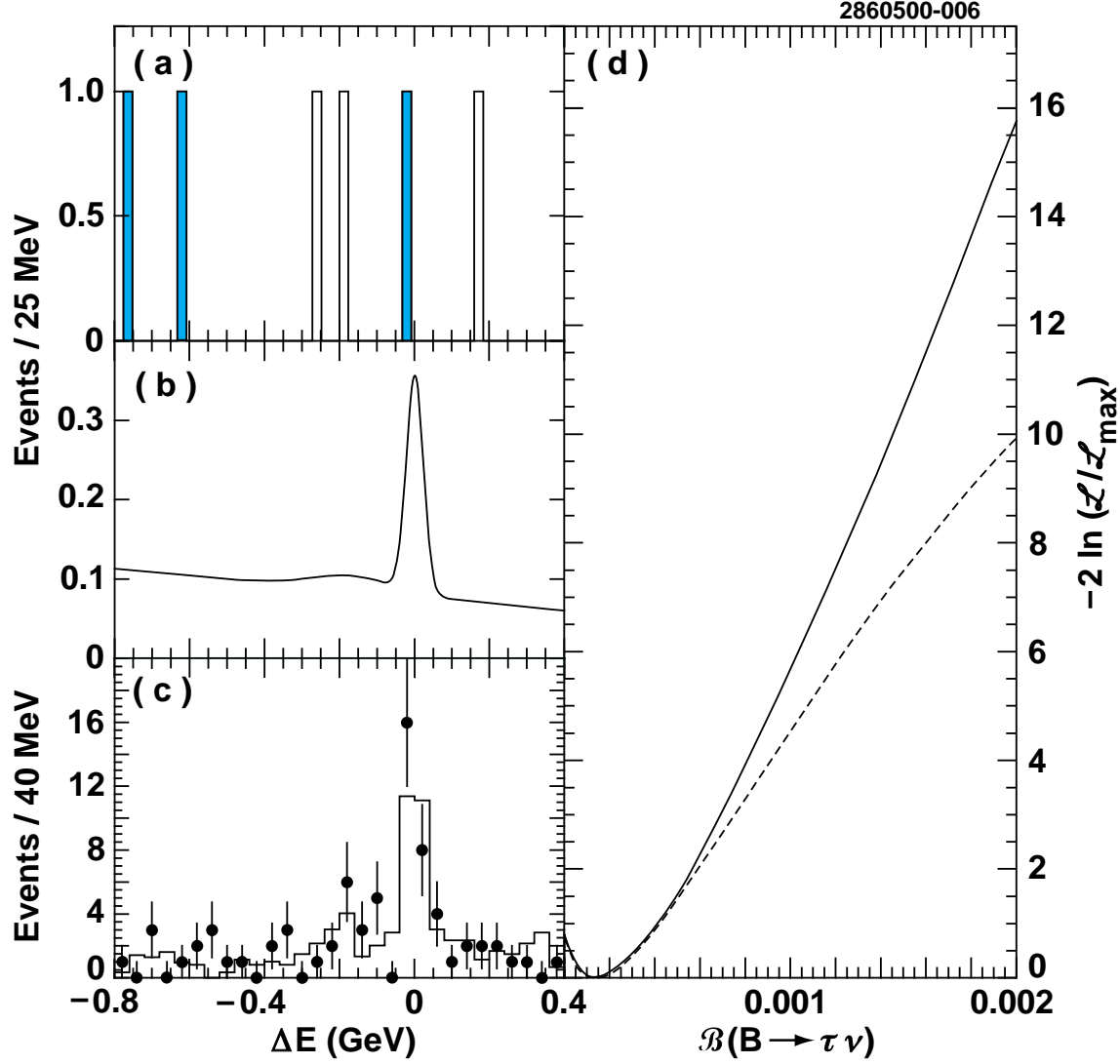


Figure 2: The results of the  $B \rightarrow \tau \nu$  search. (a) The six events that pass all selections. In the three shaded events the single track is not consistent with a lepton and these are also candidates for the  $K \nu \nu$  search. (b) The fitting shape used. (c) A comparison between data and simulation for events opposite tagging  $B$ 's, but with two extra charged tracks. (d) The log likelihood used to calculate the upper limit. The solid curve considers statistical errors only; the dashed includes systematic effects.

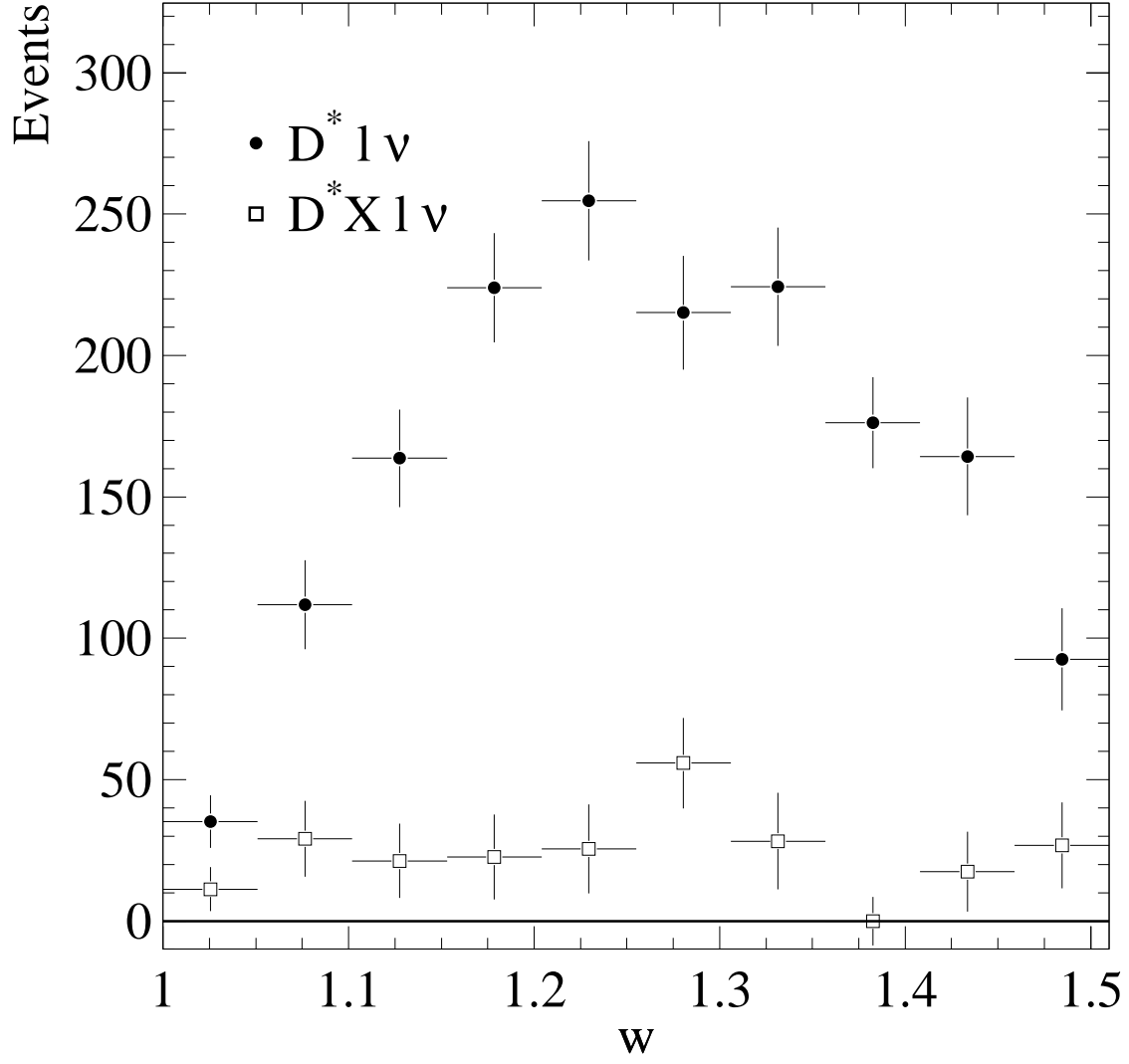


Figure 3: The  $D^* l \nu$  and  $D^* X l \nu$  yields in each  $w$  bin.

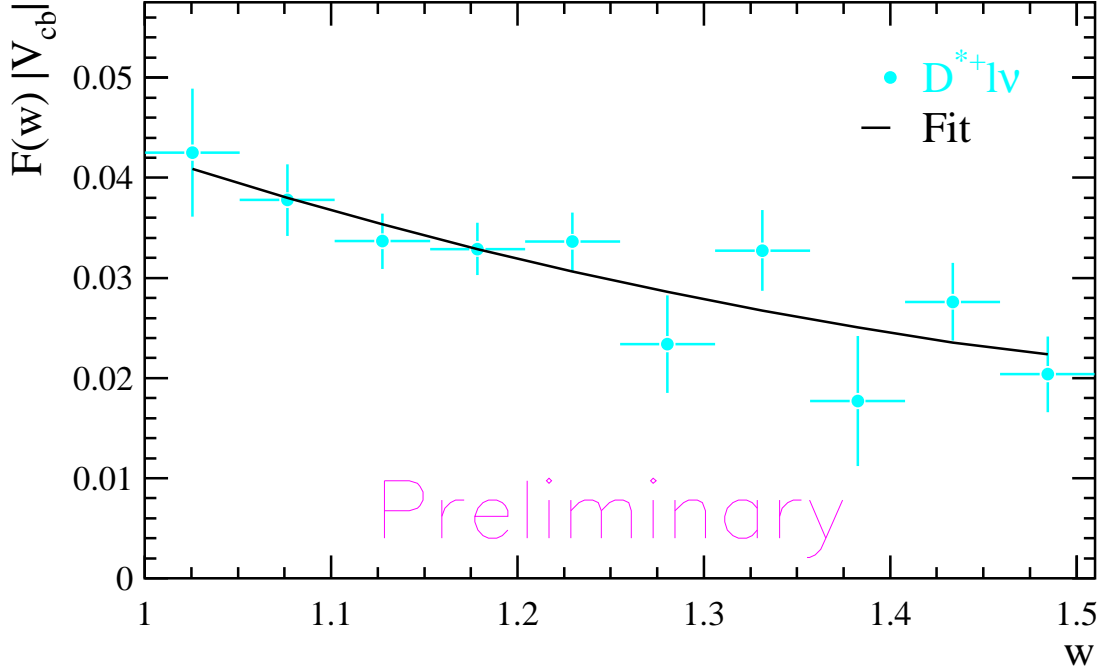


Figure 4: The result of the fit to the corrected  $d\Gamma/dw$  distribution.

The partial width is given by[12]

$$\frac{d\Gamma}{dw} = \frac{G_F^2 |V_{cb}|^2}{48\pi^3} G(w) F(w)^2 \quad (1)$$

where  $G(w)$  is a known kinematic function. The universal HQET form factor  $F(w)$  depends on two form factor ratios  $R_1(w)$  and  $R_2(w)$ , and a normalization  $h_{A_1}(w)$ . These can be constrained with dispersion relations.[13] The dependence can then be reduced to a “slope,”  $\rho^2$ , and  $R_1(1)$ , and  $R_2(1)$ . We use our measured values for  $R_1(1)$  and  $R_2(1)$ . [14] To extract the intercept we start with Figure 3 subtract the remaining background, correct for efficiency and resolution, and fit to Equation 1 with the constraints discussed above. The result is shown in Figure 4.

Systematic errors are dominated by the uncertainty in the slow pion detection efficiency as a function of momentum. The combinatoric background and the lepton ID efficiency are also important effects. For the slope the uncertainties on  $R_1(1)$  and  $R_2(1)$  are the largest effect and the branching fraction has significant uncertainty from the measurements of the  $D^* \rightarrow D\pi$  and the lepton ID efficiency. We find

$$|V_{cb}|h_{A_1}(1) = 0.0424 \pm 0.0018 \pm 0.0019, \quad (2)$$

$$\rho^2 = 1.67 \pm 0.11 \pm 0.22, \quad (3)$$

$$\mathcal{B}(\bar{B}^0 \rightarrow D^{*+} \ell^- \bar{\nu}) = (5.66 \pm 0.29 \pm 0.33)\%, \quad (4)$$



with a correlation coefficient of 0.90 between  $|V_{cb}|h_{A_1}(1)$  and  $\rho^2$ . This slope is defined differently than our previous analysis which assumed a linear dependence. If we use a linear fit we obtain consistent results. Using  $h_{A_1}(1) = 0.913 \pm 0.042$ [15] this gives

$$|V_{cb}| = 0.0464 \pm 0.0020 \pm 0.0021 \pm 0.0021 \quad (5)$$

where the last error is due to the uncertainty on  $h_{A_1}(1)$ . This result is somewhat higher than our previous result, but this is partly due to the different assumption made about the shape of  $d\Gamma/dw$ . If the same assumption is made we obtain consistent results.

## 3.2 $B^0$ Mixing

The measurement of  $B_d$ -mixing is an important cross check and provides a valuable input to the extraction CP-violation parameters in the  $b$  system. We have used a new technique at the  $\Upsilon(4S)$ [16] which combines the traditional lepton tag with a partial reconstruction of  $\bar{B}^0 \rightarrow D^{*+}\pi^-$  or  $\rho^-$ . This partial reconstruction technique only observes the fast  $\pi^-$  or  $\rho^-$  from the  $B$  decay and the slow pion from the  $D^*$  decay. This increases the statistics over the dilepton method and reduces the dilution due to charged  $B$  contamination. Also the partial reconstruction is very clean. The complete analysis has statistics of about 2000 doubly tagged events with a dilution of 13% and only 3% mistagging. This leads to the best single measure for the probability of  $B_d$  mixing of  $\chi_d = 0.198 \pm 0.013 \pm 0.014$ . Note that this measurement has very different sources of systematic errors than the lifetime based measurements from LEP and the asymmetric  $B$  factories. We can also do the analysis comparing  $B^0\bar{B}^0$  events versus  $\bar{B}^0\bar{B}^0$  and obtain limits on  $|\Re(\epsilon_B)| < 0.034$ , the  $B$  system analog of the  $\epsilon$  parameter in the  $K$  system, and combined with LEP measures of  $\Delta m_d$  and lifetime  $\Delta\Gamma_d/2\Gamma_d = |y_d| < 0.41$ , both at the 95% C.L. This is the first non-trivial limit on  $y_d$ .

## 4 Hadronic $B$ Decays

### 4.1 $B \rightarrow D^{(*)}4\pi$

Despite the large progress in the understanding of hadronic  $B$  decays, only a small fraction of the hadronic branching ratio has been measured. The majority of the measured modes are low multiplicity, and thus we are motivated to search for higher multiplicity modes. We investigate  $B \rightarrow D^{(*)}4\pi$ [17] as shown in Figure 5 and see a clear signal.

The decays  $B \rightarrow D^{(*)}(2-3)\pi$  are dominated by resonant decays to the  $\rho$  and the  $a_0$ . This motivates a search for substructure in the  $4\pi$  system. We do see a clear signal of an  $\omega$  in the  $2\pi\pi^0$  system. Combining the  $\omega$  with the remaining charged  $\pi$  we obtain Figure 6. We clearly see a resonance and determine it to have a mass of  $1418 \pm 26 \pm 19$  MeV and width of  $388 \pm 41 \pm 32$  MeV. By studying the angular distribution of the decays to this resonance we find that it has  $J^P = 1^-$ . We identify this resonance as the  $\rho'$ . This  $\rho'$  mass and width measurement are the most accurate and have little model dependence.

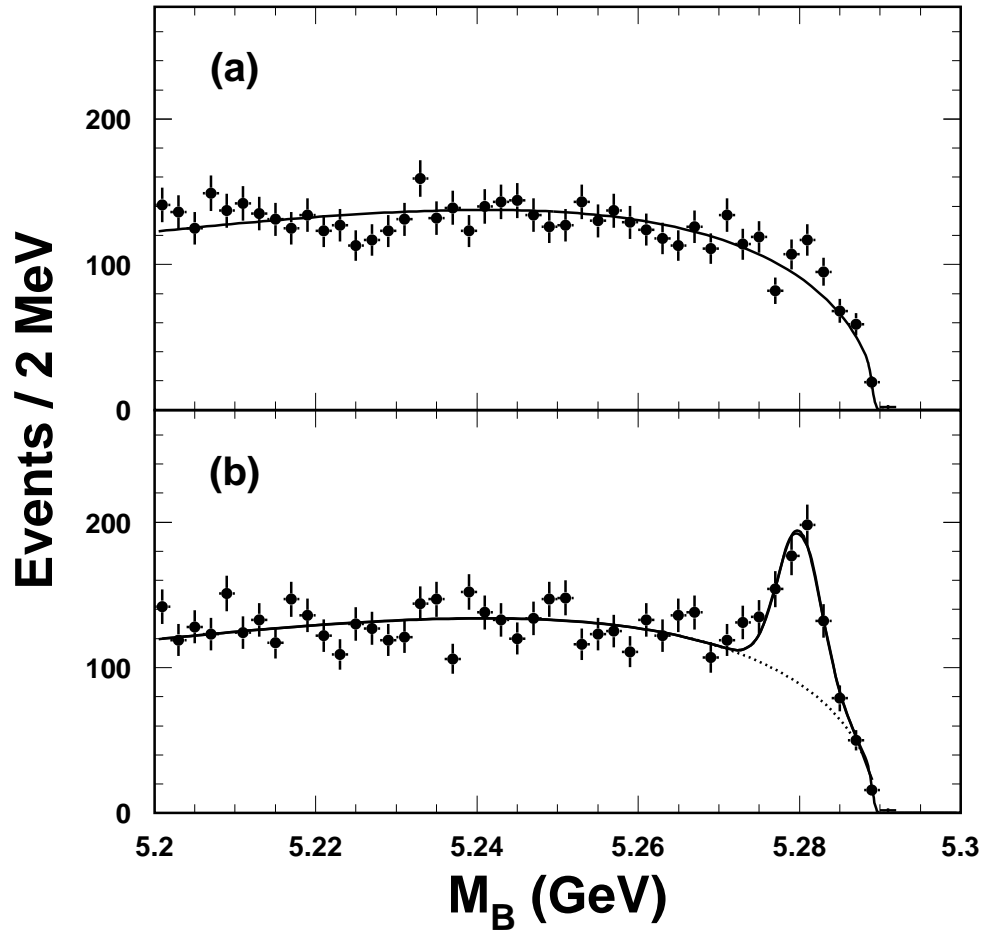


Figure 5: The beam constrained mass for  $B \rightarrow D^{*+}\pi^+\pi^-\pi^-\pi^0$  with  $D^0 \rightarrow K\pi$ . The top distribution is for a  $\Delta E$  sideband, and the bottom is for  $\Delta E$  consistent with zero.

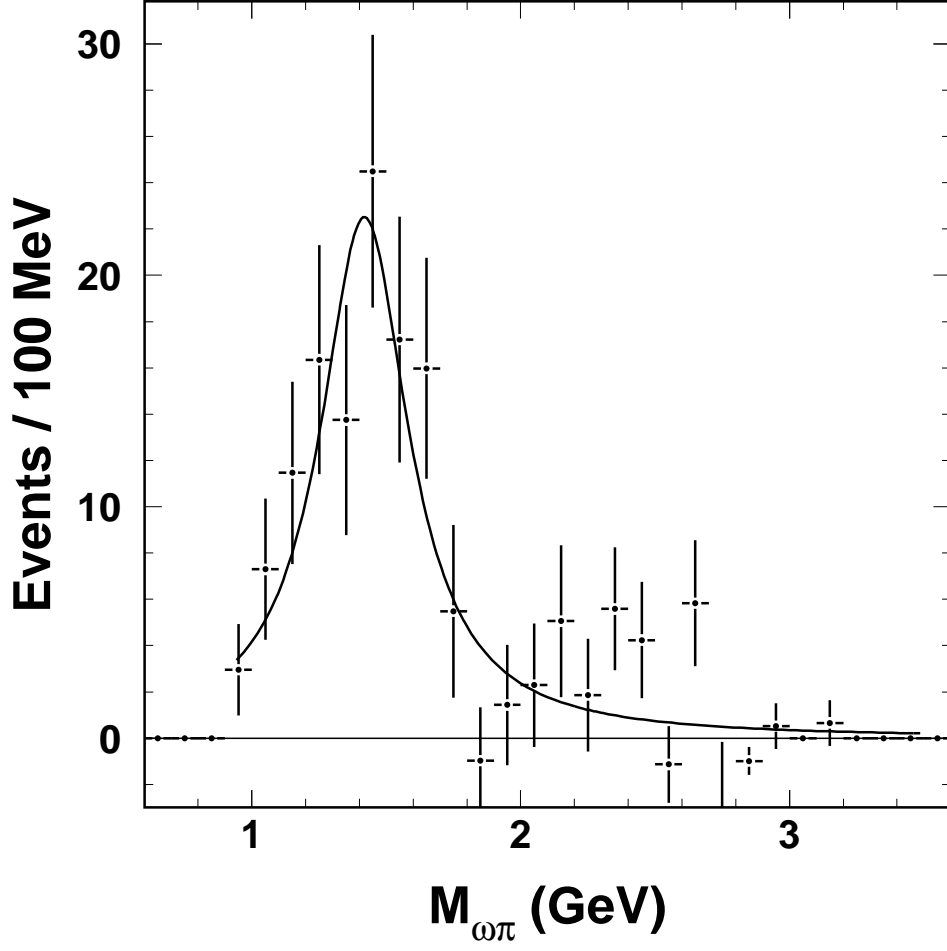


Figure 6: The invariant mass spectrum of the  $\omega\pi^-$  for the final state  $D^{*+}\pi^+\pi^-\pi^-\pi^0$  combining all  $D$  decay modes. This is the spectrum determined from fitting the yield in the beam constrained mass distribution and displaying a fit to Breit-Wigner function.

Table 3: Measured branching fractions.

Mode	$\mathcal{B}(\%)$
$B^0 \rightarrow D^{*+}\pi^+\pi^-\pi^-\pi^0$	$1.72 \pm 0.14 \pm 0.24$
$B^0 \rightarrow D^{*+}\omega\pi^-$	$0.29 \pm 0.03 \pm 0.04$
$B^0 \rightarrow D^+\omega\pi^-$	$0.28 \pm 0.05 \pm 0.03$
$B^- \rightarrow D^{*0}\pi^+\pi^-\pi^-\pi^0$	$1.80 \pm 0.24 \pm 0.25$
$B^- \rightarrow D^{*0}\omega\pi^-$	$0.45 \pm 0.10 \pm 0.07$
$B^- \rightarrow D^0\omega\pi^-$	$0.41 \pm 0.07 \pm 0.04$

Table 4: Measured branching fractions or upper limits. The third error is due to  $\eta_c$  branching fractions.

Mode	$\mathcal{B}$ or 90% C.L.U.L( $\times 10^{-3}$ )
$B^+ \rightarrow \eta_c K^+$	$0.69 \pm 0.24 \pm 0.08 \pm 0.20$
$B^0 \rightarrow \eta_c K^0$	$1.09 \pm 0.49 \pm 0.12 \pm 0.31$
$B^+ \rightarrow \chi_{c0} K^+$	$< 0.48$
$B^0 \rightarrow \chi_{c0} K^0$	$< 0.50$

Table 3 summarizes our observations in this mode. The  $\rho'$  saturates the  $\omega\pi$  final states. In the  $D^*\rho'$  modes we have measured the longitudinal polarization of the  $D^*$  to be  $63 \pm 9\%$ . This can be compared to a prediction of the factorization model that this polarization should be the same as in the semileptonic decay  $B \rightarrow D^*\ell\nu$  at  $q^2$  equal to the mass of the  $\rho'$ . The comparison of this measurement with this prediction of factorization is shown in Figure 7. The  $D^*\rho$  measure is from a previous CLEO result[18] and the  $D^*D_s$  result is discussed below.

## 4.2 $B \rightarrow \text{Charmonium}$

We have many new results on  $B$  decays to charmonium. Motivated by our observation of surprisingly large  $B$  decay rates to  $\eta'X$ [19] we search for  $B$  decays to  $\eta_c K$  and with trivial modifications to  $\chi_{c0}K$ . [20] If as has been suggested that the large  $\eta'X$  rate is due to intrinsic charm content of the  $\eta'$  then we expect an enhancement in the  $\eta_c K$  rate. Our observations are summarized in Table 4. The rates for  $\eta_c K$  are similar to those for  $J/\psi$  indicating no unexpected enhancement. Invoking factorization we can measure  $f_{\eta_c} = 335 \pm 75$  MeV also agreeing with expectation. It seems that the charm content of the  $\eta'$  is not the explanation for the anomalous  $B \rightarrow \eta'X$  decay rates.

The measurement of a large rate for high- $P_T$  charmonium at the Tevatron is a challenge to theoretical models of charmonium production.[21] An especially clean test is provided by measuring the  $\chi_{c2}$ -to- $\chi_{c1}$  production ratio in  $B$  decays.[22] Figure 8 shows our basic result. We do not see significant  $\chi_{c2}$  production, and our results are summarized in Table 5. We also

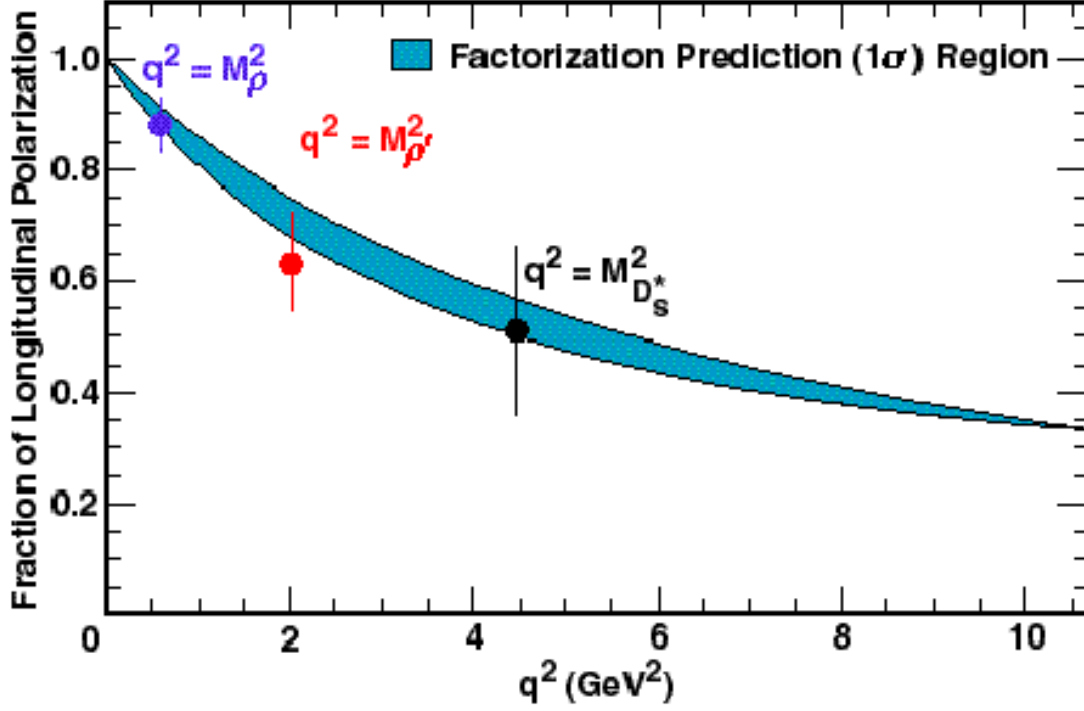


Figure 7: The fraction of  $D^*$  longitudinal polarization for three hadronic  $B$  decays. The measurements are compared with the prediction of the factorization model.

Table 5: Measured branching fractions. Direct means that feed down from  $B \rightarrow \psi(2S)$  has been subtracted

Mode	$\mathcal{B}(\times 10^{-3})$
$B^0 \rightarrow \chi_{c1} X$	$4.14 \pm 0.31 \pm 0.40$
$B^0 \rightarrow \chi_{c1}[\text{direct}] X$	$3.83 \pm 0.31 \pm 0.40$

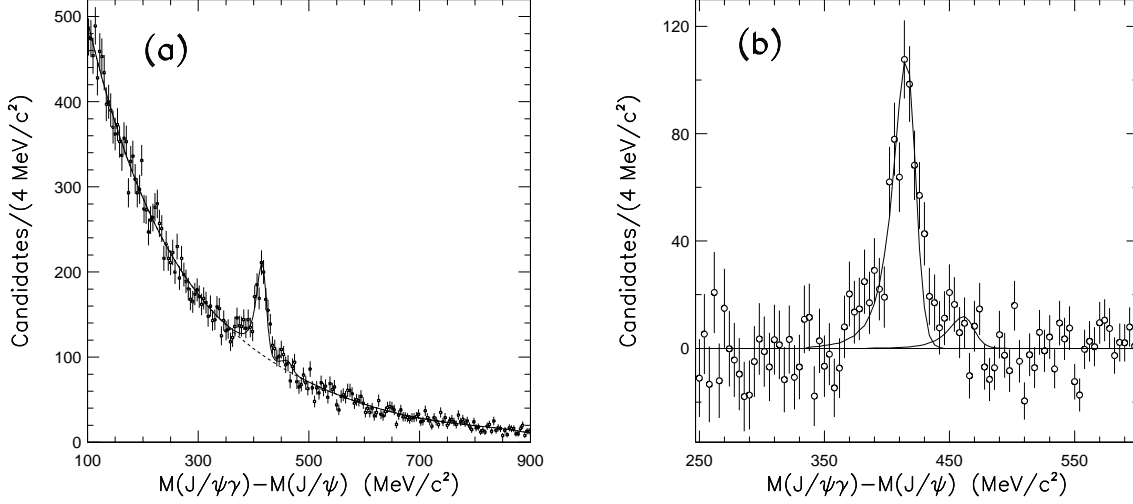


Figure 8: The  $M(J/\psi\gamma) - M(J/\psi)$  distribution. The plot on the right subtracts off the background fit displayed in the plot on the left.

limit  $\mathcal{B}(B^0 \rightarrow \chi_{c2}[\text{direct}]X)/\mathcal{B}(B^0 \rightarrow \chi_{c1}[\text{direct}]X) < 0.44$  at the 95% C.L. The results are preliminary and do not support the prediction of the color-octet model that the  $\chi_{c2}$ -to- $\chi_{c1}$  production ratio should be larger than 0.5.

We have new measurement of the exclusive two body  $B$  decays to charmonium that are being used in CP violation measurements at the asymmetric  $B$  factories:  $\mathcal{B}(B \rightarrow J/\psi K^0) = (9.5 \pm 0.8 \pm 0.6) \times 10^{-4}$ ;  $\mathcal{B}(B \rightarrow J/\psi \pi^0) = (2.5 \pm 1.0 \pm 0.2) \times 10^{-5}$ ; and  $\mathcal{B}(B \rightarrow \chi_{c1} K^0) = (3.9 \pm 1.6 \pm 0.4) \times 10^{-4}$ . [23] We have searches for direct CP violation in charged  $B$  decays to charmonium:  $\mathcal{A}_{CP}(B^\pm \rightarrow J/\psi K^\pm) = (+1.8 \pm 4.3 \pm 0.4)$  and  $\mathcal{A}_{CP}(B^\pm \rightarrow J/\psi(2S)K^\pm) = (+2.0 \pm 9.1 \pm 1.0)$ . [24] We also have precision measurements of the  $B$  meson masses in  $B \rightarrow \psi^{(\prime)} K$ :  $m(B^0) = 5279.1 \pm 0.7 \pm 0.3$  MeV and  $m(B^+) = 5279.1 \pm 0.4 \pm 0.4$  MeV. [25]

### 4.3 $B \rightarrow D_s^{(*)} D^*$

There is a substantial discrepancy between the inclusive and sum of the exclusive  $B$  decays to  $D_s$ . We have used a new technique where a fully reconstructed  $D_s \rightarrow \phi\pi$  is combined with a partially reconstructed  $D^*$ , whose soft pion is the only observed decay product, to measure exclusive  $B$  decays to  $D_s$ . [26] This partial reconstruction technique results in much higher statistics than previous analysis, and much more accurate measurements can be made. We observe evidence for  $B \rightarrow D_s^{(*)} D^{*0}$  decays. The results are summarized in Table 6. We also measure the longitudinal polarization of the  $D_s^* D^{*-}$  production to be  $(51 \pm 14 \pm 4)\%$ . This is compared with the prediction of factorization in Figure 7, and agrees well.

Table 6: Measured branching fractions. The third error is due to the  $D_s \rightarrow \phi\pi$  branching fraction.

Mode	$\mathcal{B}(\%)$
$B^0 \rightarrow D_s D^{*-}$	$1.01 \pm 0.18 \pm 0.10 \pm 0.28$
$B^0 \rightarrow D_s^* D^{*-}$	$1.82 \pm 0.37 \pm 0.24 \pm 0.46$
$B^+ \rightarrow D_s^{(*)} D^{*0}$	$2.73 \pm 0.78 \pm 0.48 \pm 0.68$

Table 7: Measured branching fractions.

Mode	$\mathcal{B}(\times 10^{-4})$
$B^0 \rightarrow D^{*-} p \bar{p} \pi^+$	$6.6 \pm 1.4 \pm 1.0$
$B^0 \rightarrow D^{*-} p \bar{n}$	$14.5 \pm 3.2 \pm 2.7$

## 4.4 $B \rightarrow$ Nucleons

A unique feature of the  $B$  meson is that the large mass of the  $b$  quark allows weak decays to baryon-anti-baryon pairs. Measurements of the inclusive rate of  $B \rightarrow \Lambda_c X$  lead to estimates that the  $B \rightarrow \bar{\Lambda}_c N X$ , where  $N$  is a proton or neutron, rate accounts for only half of the baryon production observed in  $B$  decays. We are thus motivated to search for  $B \rightarrow D N \bar{N} X$ . [27] We do observe such decays in the modes and with rates given in Table 7, and the signals are displayed in Figure 9. Note that the  $B^0 \rightarrow D^{*-} p \bar{n}$  mode is observed via the annihilation of the  $\bar{n}$  in our calorimeter. We are not sensitive to the charge conjugated mode with a  $n$ . These measurements account for a substantial fraction of the non- $\Lambda_c$   $B$  to baryon decay rate.

# 5 Charm Physics

## 5.1 $D^0$ Mixing and Doubly Cabibbo Suppressed Decays

One of the most exciting areas in the last year has been new probes with a factor of three more sensitivity for  $D$ -mixing and Doubly Cabibbo Suppressed Decays (DCSD). [28] We are working hard at CLEO to make use of our clean event environment to search in many  $D$  decay modes to improve on our results. All of these analyses are only done with the superior vertex resolution of the CLEO II.V detector.

The latest work is preliminary. We do have a significant wrong sign signal in  $D \rightarrow K \pi \pi^0$  decay, shown in Figure 10, of  $39 \pm 10 \pm 7$  events compared to a right sign yield of over 9000. We are working hard to turn this yield into a rate, but the Dalitz structure of the wrong sign decay may be different than the right sign decay leading to a difference in efficiency for mixed and DCSD wrong sign events. The resonance substructure for  $D \rightarrow K \pi \pi^0$  is very

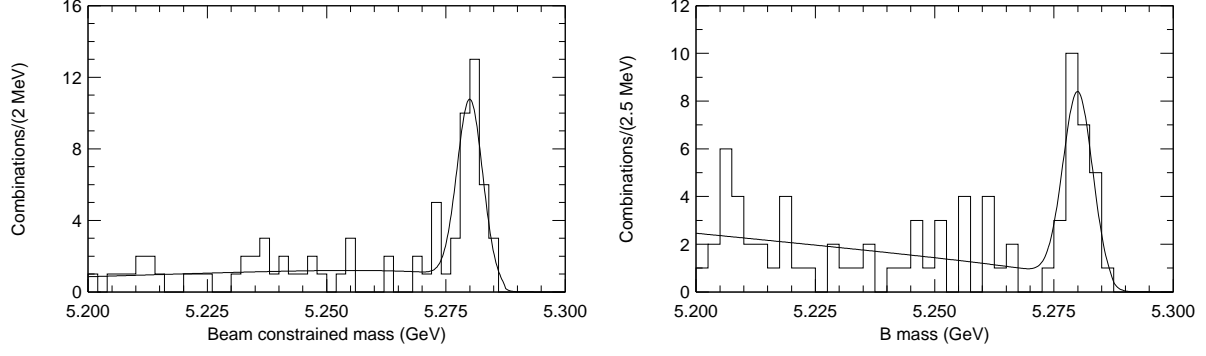


Figure 9: The beam constrained mass for the  $B \rightarrow D N \bar{N} X$  signals. On the left is  $D^{*-} p \bar{p} \pi^+$  and on the right is  $D^{*-} p \bar{n}$ .

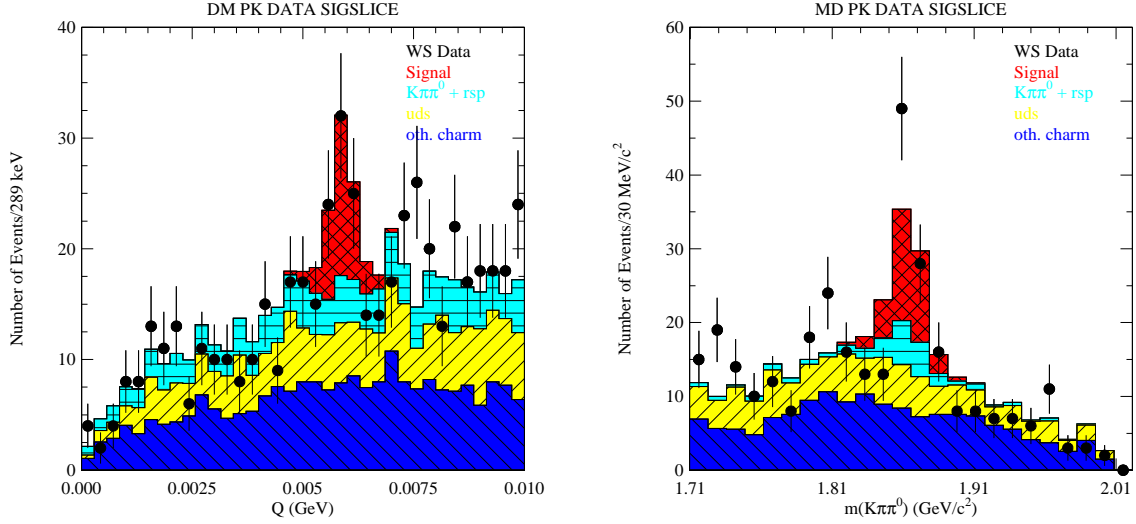


Figure 10: The wrong sign  $D \rightarrow K \pi \pi^0$  signal. On the right is the  $Q$  distribution and on the left is the  $K \pi \pi^0$  invariant mass.



rich with three dominant modes clearly visible in the Dalitz plot for the right sign signal shown in Figure 11, clear signs of interference, and many other smaller amplitudes that can contribute.

We are also working on the lifetime analyses of the  $K\pi\pi^0$  mode; the CP even eigenstates  $KK$  and  $\pi\pi$ ; CP odd eigenstates  $K_s^0\phi$ ,  $K_s^0\rho^0$ , and  $K_s^0\omega$ ; and in the semileptonic decays  $K\ell\nu$  and  $K^*\ell\nu$ . One of the first steps on this road is a preliminary measure of the CP asymmetries  $\mathcal{A}_{CP}(D^0 \rightarrow KK) = (+0.04 \pm 2.18 \pm 0.84)\%$  and  $\mathcal{A}_{CP}(D^0 \rightarrow \pi\pi) = (+1.94 \pm 3.22 \pm 0.84)\%$ .

## 5.2 Charm Baryons

There are a great many results on charm baryons, and I can only cover the very highest points, and even these only briefly. We have a first observation of the  $\Sigma_c^{*+}$  and a new measure of  $\Sigma_c^+$  mass both in  $\Lambda_c\pi^0$  decay.[29] The data is shown in Figure 12 showing the clear signals.

We make the first observation of the  $J^P = 1/2^-$  pair  $\Xi_{c1}^+$  and  $\Xi_{c1}^0$ . [30] Note that this result combined with the observation of the  $\Sigma_c^{*+}$  discussed above means that all of the  $L = 0$  single charm baryons have been observed. The majority of these have had their first observation by CLEO.

In a preliminary result we see two states in decays to  $\Lambda_c\pi^+\pi^-$ ; a wide state decaying to  $\Sigma_c$  and  $\Sigma_c^*$ , possibly an orbitally excited  $\Sigma_{c1}$ , and a narrow state decaying to  $\Sigma_c\pi$  and non-resonant, possibly an excited baryon with  $L = 1$  between the light quarks.[31] The data is shown in Figure 13. Our interpretation of these two states is guided by the observed mass and width rather than any observation of the angular distribution of their decays.

CLEO has observed the  $\Omega_c$  and made a precision measure of its mass,[32] and we have a new measurement of the  $\Lambda_c$  branching fraction into  $pK\pi$ . [33]

## 6 Other Physics Results

### 6.1 $\Upsilon(4S)$ Charged and Neutral Decay Fraction

From the relative rates for  $B^0 \rightarrow J/\psi K^{(*)0}$  and  $B^+ \rightarrow J/\psi K^{(*)+}$  we are able to measure the relative branching fraction of the  $\Upsilon(4S)$  to charged and neutral  $B$  mesons.[34] We find

$$\begin{aligned} \frac{f_{+-}}{f_{00}} &\equiv \frac{\Gamma(\Upsilon(4S) \rightarrow B^+ B^-)}{\Gamma(\Upsilon(4S) \rightarrow B^0 B^0)} \\ &= 1.04 \pm 0.07 \pm 0.04 \end{aligned} \tag{6}$$

and assuming  $f_{+-} + f_{00} = 1$ , that is the  $\Upsilon(4S)$  only decays to  $B\bar{B}$ ,  $f_{+-} = 0.49 \pm 0.02 \pm 0.01$  and  $f_{00} = 0.51 \pm 0.02 \pm 0.014$ .

## Right-sign Data

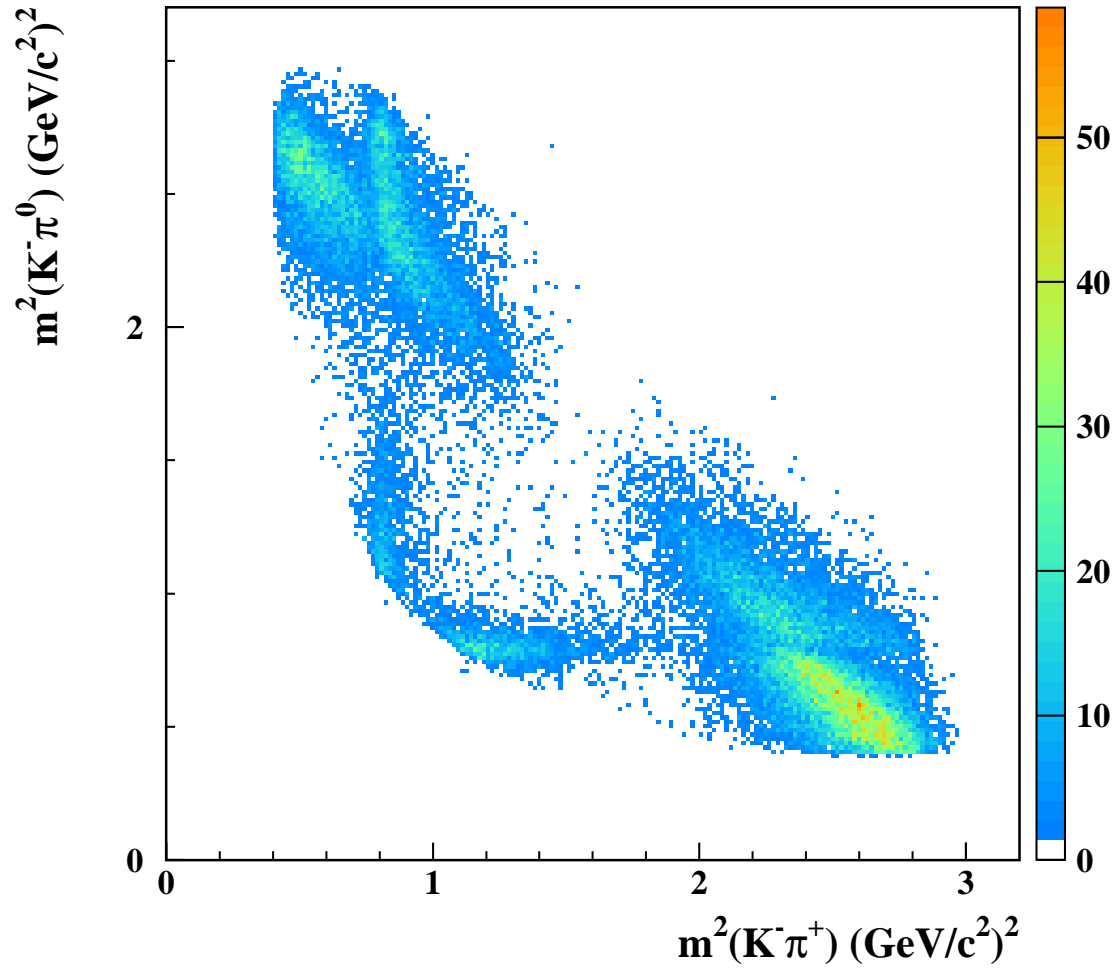


Figure 11: The Dalitz plot for right sign  $D \rightarrow K\pi\pi^0$  decay in the CLEO data.

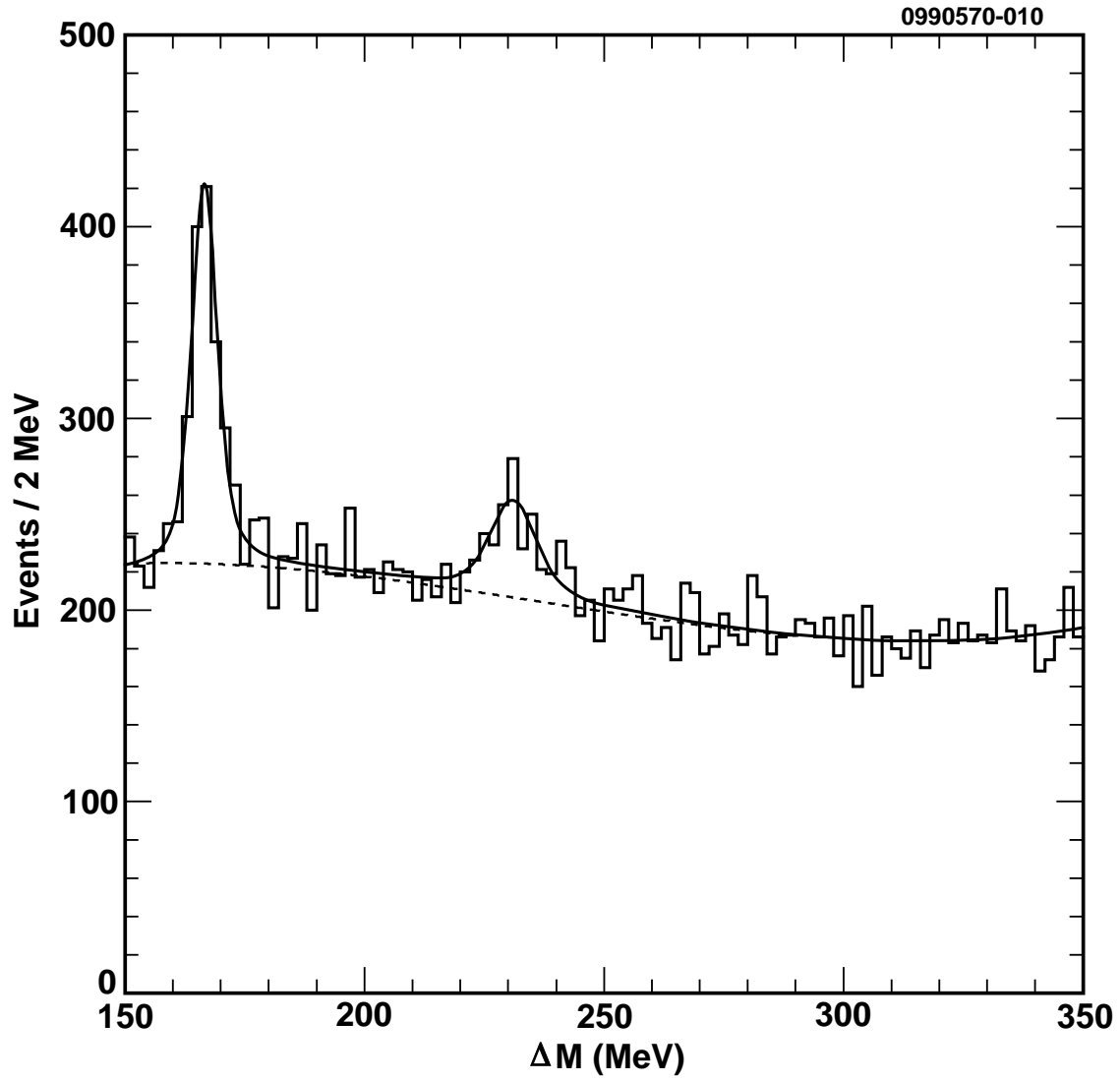


Figure 12: The distribution of  $M(\Lambda_c \pi^0) - M(\Lambda_c)$  showing the narrow  $\Sigma_c^+$  and wide  $\Sigma_c^{*+}$ .

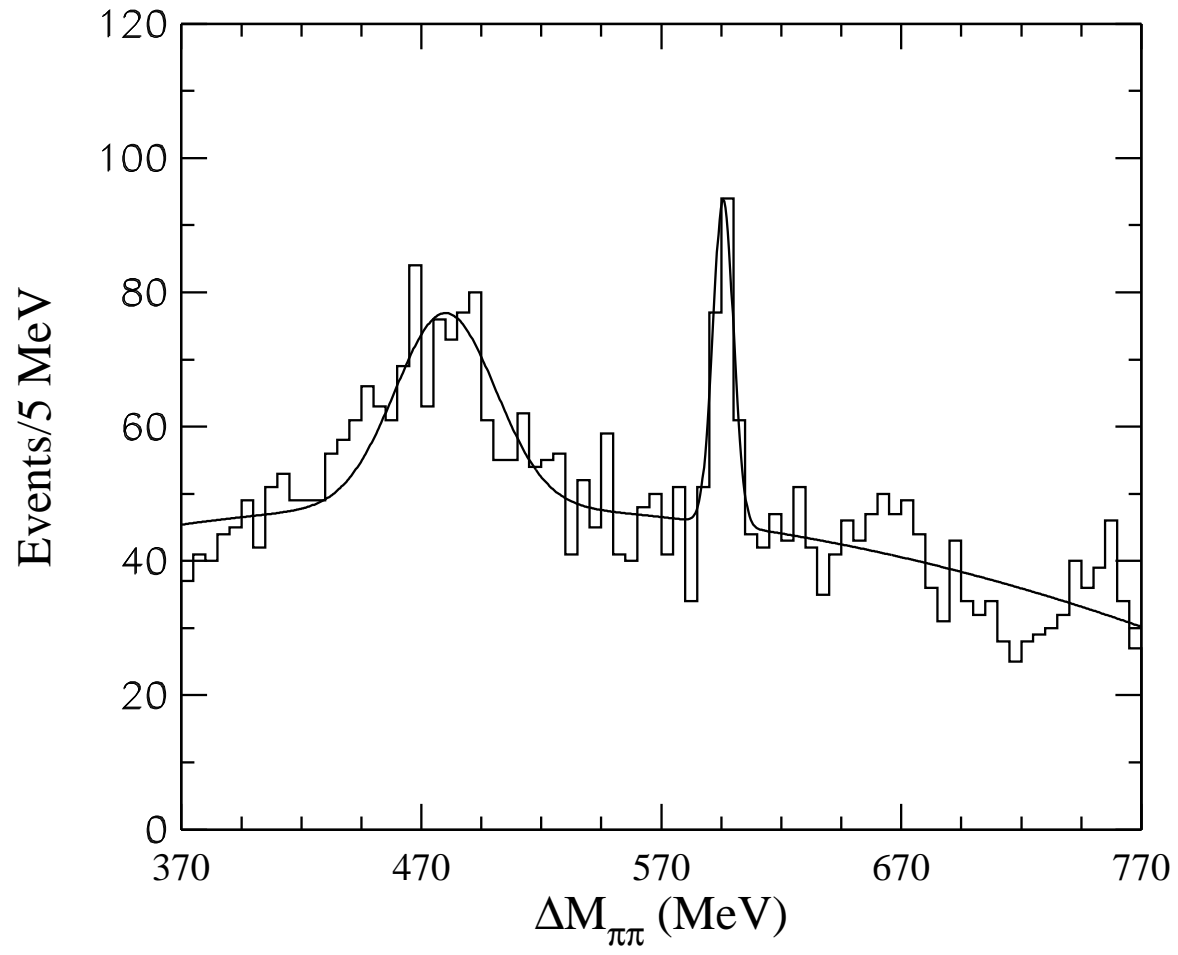


Figure 13: The distribution of  $M(\Lambda_c \pi^+ \pi^-) - M(\Lambda_c)$  showing the two new states.

## 6.2 $\eta_c$ in $2\gamma$

We have observed 300 events of the two photon production of the  $\eta_c$ . [35] We measure  $m(\eta_c) = (2980.4 \pm 2.3 \pm 0.6)$  MeV,  $\Gamma(\eta_c) = (27.0 \pm 5.8 \pm 1.4)$  MeV, and the two photon partial width  $\Gamma_{2\gamma}(\eta_c) = (7.6 \pm 0.8 \pm 0.4 \pm 2.3)$  keV, where the last error is from the branching fraction of the  $\eta_c$  into  $K_s^0 K^\mp \pi^\pm$ . This last observation agrees much better with the prediction of Perturbative QCD based on the  $e^+e^-$  partial width of the  $J/\psi$ .

## 7 CLEO III Status

The CLEO II.V detector ceased data taking in February of 1999. It has been upgraded to the CLEO III detector. The upgrade consists of a new four layer double sided silicon drift detector, a new 47 layer drift chamber, much stronger particle ID with the addition of a new barrel RICH, refurbished CsI calorimeter and muon system, and a new data acquisition and trigger system that are designed to handle delivered luminosity of up to  $5 \times 10^{33}/\text{cm}^2\text{-sec}$ . The upgraded detector was completed in April of 2000 and started taking physics data in July of 2000.

The new detector is performing well with a tracking system already working as well as the CLEO II configuration, and a much improved resolution on photons in the calorimeter endcaps due to the reduction of support material in the upgrade from the old to the new drift chamber. The RICH is also performing very well with a preliminary efficiency of around 90%, and an intrinsic resolution on the Cherenkov angle of 2-4 mrad.

## 8 Conclusion

There is a vast array of physics results to be had from the  $\Upsilon(4S)$ . Highlights from CLEO in the last six months are an unambiguous observation of the gluonic penguin, the best single measure of  $|V_{cb}|$ , and the first observation of a high multiplicity hadronic  $B$  decay mode. There are many other results and with the beginning of CLEO III data taking and first results from the asymmetric  $B$  factories we can all look forward to much more exciting physics from the  $\Upsilon(4S)$  in the future.

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